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GEOGRAPHY AS HUMAN ECOLOGY.*

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GEOGRAPHY AS THE MOTHER OF SCIENCES.—Only in recent years has geography been recognized to any extent in America as an appropriate subject for university instruction and research, as a science with vital truths to contribute to human knowledge, and as an art having wide application to practical affairs. One is not surprised, therefore, to hear it frequently characterized as the youngest of the subjects of advanced study. It is of course unnecessary to remind this audience that geography, on the contrary, properly can claim the title of Mother of the Sciences. Centuries before Christ it was a recognized study whose field embraced the entire universe. As time passed, geography bore many children, among them astronomy, botany, zoology, geology, meteorology, archæology, and anthropology. Some of its offspring have pursued independent careers in the world of science for so long a time that, quite naturally, their relation to the mother subject commonly is entirely overlooked. Each attained its independence by taking over a part of the parental estate whose cultivation involved distinctive tasks and by working it more intensively than the parent had done. Thus each child became a successful specialist, while the parent, though it relinquished most of its original domain and many of its earlier functions, still retained multifarious interests. Moreover, geography re-

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peatedly has undertaken new obligations as marginal fields have become new centers for research, and so has added to the complexity and extent of its domain. In other words, its boundaries expanded in some quarters, even as they contracted in others. Thus the scope of geography has changed from time to time in the past, and future changes may be anticipated with confidence. Geography perhaps will remain for many years a "vibrant science."

Under such circumstances it doubtless is inevitable that divergent opinions should obtain concerning the content and scope of geography, and that questions should arise concerning the future of the subject. Discussion of these matters is by no means confined to America, as some have appeared to think. For example, Hogarth, in the course of his Presidential Address last year to Section E of the British Association, said: "Ever losing sections of her original field and functions, ever adding new sections to them, geography can hardly help suggesting doubts to others and even to herself. There must be a certain indefiniteness about a field on whose edges specialisms are forever developing towards a point at which they will break away to grow alone into new sciences. The mother holds on awhile to the child, sharing its activities, loath to let go, perhaps even a little jealous of its growing independence. It has not been easy to say at any given moment where geography's functions have ended and those of, say, geology or ethnology have begun. Moreover, it is inevitably asked about this fissiparous science from which function after function has detached itself to lead life apart—what, if the process continues, as it shows every sign of doing, will be left to geography later or sooner? Will it not split up among divers specialisms, and become in time a venerable memory?" Though they have been discussed in various quarters, such questions perhaps have nowhere received more attention of late than in this country. The members of this Association will recall especially the Presidential Address of Fenneman, in which he asked the question, "Suppose geography were dead, what would be left?" and proceeded to consider a possible partition of geography's domain. Hogarth, Fenneman, and, so far as I know, all other competent geographers who have spoken on the subject, assure us that there is no possibility that geography will be moribund, because it has a necessary and distinctive task to perform which other sciences cannot discharge. Doubtless all geographers concur in this view, but quite as certainly there is disagreement among them as to the precise nature of the distinctive task in question. Geography is not at all peculiar, as sometimes suggested, in that the twilight zone by which it is bounded is both vague and unstable. This is true also of geology, botany, economics, history, sociology, and various other subjects. But it per-

haps is peculiar in that radical differences of opinion exist among its exponents concerning its *distinctive functions,* concerning its *center*—to borrow Fenneman's figure of four years ago.

HUMAN ECOLOGY AS THE UNIQUE FIELD OF GEOGRAPHY—What then, is the concept that marks out a distinctive field for geography? The answer to this question is foreshadowed, it seems to me, by recent tendencies in geographic work in various European countries, notably in France and Great Britain, and especially by developments in America. The rise of what we are pleased to call modern scientific American geography has occurred within scarcely more than a quarter of a century. It began with the brilliant work of Davis, Gilbert, and a few others in physiography,—or in physical geography, as it sometimes was called. It is a singular fact, which may be recalled in passing, that geography, though it is the mother of geology, has, in the recent period which has witnessed its revival in America as a subject of higher study, been fostered by geology. In one university after another work in geography has been offered first in the Department of Geology. As this work increased, the official title of the department in not a few cases was changed to "The Department of Geology and Geography." This is the status of things now in seven or eight of the leading universities of the Interior. Scarcely was physical geography established, or perhaps I should say rejuvenated and reestablished, before an insistent demand arose that it be "humanized." This demand met with a prompt response, and the center of gravity within the geographic field has shifted steadily from the extreme physical side toward the human side, until geographers in increasing numbers define their subject as dealing solely with the mutual relations between man and his natural environment. By "natural environment" they of course mean the combined physical and biological environments.

Thus defined, geography is the science of *human ecology.* The implications of the term "human ecology" make evident at once what I believe will be in future the objective of geographic inquiry. Geography will aim to make clear the relationships existing between natural environments and the distribution and activities of man. Geographers will, I think, be wise to view this problem in general from the standpoint of man's adjustment to environment, rather than from that of environmental influence. The former approach is more likely to result in the recognition and proper valuation of all the factors involved, and especially to minimize the danger of assigning to the environmental factors a determinative influence which they do not exert.

It has been said by some that though the foregoing definitional statements indicate a field for human ecology, they cannot do so for geography because the latter term has a fixed connotation. Quite the

contrary. If the history of geography teaches one lesson more clearly than another, it is that the etymology of the word has not delimited the field to which it applies. In the future, just as in the past, the scope of geography will be determined largely by that of the constructive work of its followers and by the labors of men in kindred fields.

THE RELATION OF GEOGRAPHY TO OTHER SUBJECTS.—The conception of geography as human ecology would, it seems to me, help materially to dispose of the much-discussed problem of its alleged overlap with certain other subjects. In order to show the interactions between man and a particular environmental complex, geography would, of course, deal with the various elements of the complex—with land forms, soils, climate, vegetation, and so on through the familiar list. It would not, however, be the business of geography to explain the origin, character, and occurrence of these environmental features, nor their relations one to another, but to examine the responses of man to them, considered individually and in combination. Let me be more explicit. Physiography, as an abstract study of the evolution of land forms, has been claimed for geology, whereas regional physiography has been held by some to be a part of geography. It never has been clear to my mind that a body of facts and principles is shifted from one science to another *merely* by giving it areal application. In any event, geography defined as human ecology would not be concerned with the genesis and development of land forms in particular areas or in general, but with the adjustments of man to land forms as elements of the natural environment. In other words, the interests of geology and geography in land forms would be mutually exclusive. In a similar way, geography as human ecology would not be concerned with an explanation of the character and distribution of the different climates of the world, but with the human relations of climate, commonly as one element merely of an environmental complex. Again, geography would not deal with the relations of plants and animals to their physical environment, but with plants and animals as elements of the natural environment affecting man. In short, geography treated as human ecology will not cling to the peripheral specialisms to which reference has been made—to physiography, climatology, plant ecology, and animal ecology—but will relinquish them gladly to geology, meteorology, botany, and zoology, or to careers as independent sciences.

It may be well explicitly to state at this point what already has been implied. Title to any of these fields can be established only by their successful cultivation, and for the most part productive research in them is not being carried on by geographers. The foregoing statements are not intended for the briefest moment to imply that the geographer will not need a technical knowledge of those environmental features,

the origin, character, and occurrence of which are explained by these other sciences. On the contrary such a knowledge is an indispensable prerequisite to successful geographic work. It may be added, however, that in some cases the treatment of these environmental features by other sciences is not of the type that best fits the needs of the geographer. Physiography, for example, seemingly has failed to produce a classification of certain land forms suitable for geographic purposes.

In considering the external relations of geography, most attention has, I think, been given by American geographers to its points of contact with the physical and biological sciences to which reference has just been made. This has been a natural result of the history of the subject in this country. In the immediate future, however, increasing attention doubtless will be given to its relations to the social sciences. It is not our province to attempt to define these sciences with exactitude —this is a task which the social scientists themselves apparently have not accomplished to their mutual satisfaction—but it is essential that we try to differentiate these fields from geography, and so it is necessary that we form, if possible, a clear conception of the particular phase of human affairs to which each one gives a unique or dominant attention. What is the particular point of view from which economics, history, sociology, and political science deal with the development of man and his civilization, with the complex and interrelated aspects of human activity?

The unique problem of the economists apparently is the analysis of the economic structure of society and the formulation of economic generalizations or laws for the guidance of individuals and groups. Thus economics considers the activities that man pursues in appropriating or adapting natural resources to his material wants with a view especially to understanding those institutions and processes of society which these activities have induced, and by which in turn they are in part conditioned. In short, economics seeks to explain certain relations among men, relations many of which arise from man's utilization of the resources of the earth, while geography seeks to explain certain relations between man and the earth.

Some historians assert that the aim of history is to portray and explain the whole development of civilization. One perhaps need not quarrel with this program for history, which would deny to the other social sciences and to geography their separate fields, for it assuredly will remain an unattainable ideal. The historian cannot explain everything, however great his ambition may be. Scientific history is concerned with tracing the evolutionary development through the ages, of specific social groups, institutions, movements, and ideas. History, therefore, deals largely with the past. Geography proper deals

largely with the present. Historical inquiry begins with the fragmentary records of man recoverable from the dim mists of antiquity; geographical inquiry finds its most effective point of departure, as Brunhes has urged, with those surface manifestations of man's present occupation of the earth which make up the cultural landscape. The historian, in other words, begins his studies with what our remote ancestors saw; the geographer begins with what we ourselves see. History is concerned with *time* relations; chronology is its organizing principle. Geography is concerned with *place* relations; ecology may well be its organizing concept. History and geography therefore deal with human affairs from contrasted view points, employ dissimilar methods, and arrive at generalizations of a different nature.

Sociologists have found it peculiarly difficult to define a distinctive field for their subject, and yet the contributions of sociology to knowledge have been of the first order of importance. Like history, it traces and helps to explain the processes and the progress of social development. In so doing, however, it deals, in contrast with history, largely with *types* of social organizations and of social institutions. It analyzes the relations of man to man, of man to group, of group to man, and of group to group with a view to disclosing the existence and operation of laws of association. In so doing it deals, for example, not with particular individuals, but with any individual at a given stage of development. It analyzes social development, characterizes in generalized terms the processes concerned in it, and defines the stages involved, all in such a way that its findings function vitally in the historical interpretation of the social development of any given group of people. Thus history becomes, in a measure, *applied* sociology. Sociology also seeks to provide a technique for the study of contemporary social life, and through such study to develop principles for the guidance of social service. While sociology has given some attention to the relation of society to the natural environment, especially in connection with social origins as expressed in the life of primitive people, this branch of human ecology has not been systematically studied, nor can it be until both geography and sociology have made further progress. Whether this work will be done chiefly by geographers or by sociologists is not apparent. Evidently sociology always will deal very largely with cultural relations among men, that is to say with the social environment of man, and this clearly differentiates the center of its field from that of geography.

Political science perhaps has the most sharply defined field of the social sciences. It deals with the political structure of society, with the regulation, restraint, and promotion of human activity through law and governmental action, and seeks to give an understanding of the

principles that underlie all the functions of government. It has to do exclusively with the political environment of man, and so is set apart from geography.

Geography finds in human ecology, then, a field cultivated but little by any or all of the other natural and social sciences. Thus limited in scope it has a unity otherwise lacking, and a point of view unique among the sciences which deal with humanity. Through a comparative study of human adjustment to specific natural environments, certain reliable generalizations or principles have been worked out, while many others have been suggested tentatively. These are the requisites of any science: a distinctive field, and a controlling point of view by means of which its data may be organized with reference to the discovery of general truths or principles.

THE DIVISIONS OF SYSTEMATIC GEOGRAPHY.—If geography be regarded as human ecology, three major systematic divisions of the subject are at once to be recognized, namely economic geography, political geography, and social geography, corresponding to the three great types of human activity that are related to the earth.

According to this scheme, economic geography would seek to account for those adjustments of man to his environment which are associated with the getting of a living. Among its subdivisions would be agricultural geography, pastoral geography, the geography of extractive industries (mining, logging, fishing, etc.), commercial geography, and the geography of manufacturing. Economic geography is the best developed division of the subject, doubtless because most of the activities with which the economic geographer is concerned involve the direct utilization of earth resources and result in various readily discernible surface features which help to make up the cultural landscape. Economic geography also is the most fundamental division of the subject.

If geography as a whole be regarded as human ecology, the viewpoint of political geography follows as a matter of course. It aims to account for such relationships as may exist between man's political attitudes, activities, and institutions, on the one hand, and the natural environment on the other. Such connections must be established in most cases through the facts of economic geography, and not directly. Failure to recognize this, and to proceed accordingly, invites untenable generalizations and helps to make much so-called political geography really political history, with at best a geographic slant.

Theoretically at least there is a definite field for social geography, which would study the connections that may exist between the social life of peoples and their natural environments. But the facts of "living" are intangible and for the most part find any connections which

they may have with the natural environment through the facts involved in "getting a living." As already suggested in connection with sociology, this body of relationships appears to form a potential field for geography rather than an assured field.

Regional Geography.—We come now to regional geography, properly recognized as the culminating branch of the science because it involves facts and principles from all the divisions and subdivisions of systematic geography. As you would expect from the statements already made, I believe that regional geography, even in its widest sense, properly is concerned only with the mutual relations between men and the natural environments of the regions or areas in which they live. I realize fully that here again I depart widely from the viewpoint of most geographers. It has been pointed out that any environmental element (topography, soil, climate, vegetation, etc.) can be studied with reference to the facts and causes of its distribution and it has been urged that such a treatment is the function of regional geography. Does the world of science look to geography for this service? Does not geology, for example, explain the distribution of volcanoes, and zoology that of fishes? Could *any* one science hope really to explain the distribution of all the phenomena of the earth's surface with which science in general is concerned? Are not the technical methods of inquiry too diverse and the field too vast? How much would the other sciences know about the causation of the distributions with which they deal if they had waited upon geography for the information? How *can* certain geographers seriously "claim for geography to the exclusion of any other science, all study of spatial distribution on the earth's surface"? Again it is urged that in any event regional geography comes into its own when the synthetic element is introduced, and the different items are studied in the light of their interactions upon one another. Proponents of this view hold, moreover, that such a study of inter-relationships in an uninhabited area would still be of the essence of geography. It does not seem to me, however, that geography has any function to perform in connection with such studies of non-human relationships. All the more significant interactions of the natural surface elements are considered by other sciences without recourse to geography. Thus physiography considers the influence of vegetation on the development of land forms, and botany takes account of the effect on plant life of topography, soil, and climate. A consideration of an uninhabited region gains geographic quality, as it seems to me, only when the environmental elements there existing are considered, particularly in conjunction, from the standpoint of the advantages and disadvantages of the region for human occupation and use. Even though the en-

vironmental conditions of a region preclude human habitation, it may be studied profitably from the viewpoint of the human ecologist. The thesis I am trying to maintain is that a regional treatment has geographic quality only when the governing concept throughout is human ecology. The usual treatment has chapters on physiography, climatology, botany, economics, history, etc., and though each has a special unity in itself, there is no scientific unity to the whole and certainly no geographic concept which prevails throughout, so that, as noted by one of my predecessors in this chair, entire chapters might be transferred bodily to monographs, for example, on economics or history. The possibility of such transfer stamps the treatment as non-geographical. Doubtless there will be a demand for scholarly treatises on many regions which will present all that is known of significance about the regions, but let us not call all such diversified information geography, or suppose that it can be provided by geographers alone or by the followers of any other single science. Fenneman has told us that "the center of geography is the study of areas." Even an extended study of an area need not, however, involve any real geography. I should like, accordingly, to suggest as a substitute the idea that "the center of geography is the study of human ecology in specific areas." This notion alone holds out to regional geography a distinctive field, an organizing concept throughout, and the opportunity to develop a unique group of underlying principles.

Two basic problems in economic regional geography, problems closely related to each other but yet distinct, are (1) how does man use the land and its resources, and why does he use them as he does? and (2) what are the advantages and disadvantages, the opportunities and handicaps, of the region for utilization by man? The first problem involves an interpretation of existing economic adjustments; the solution of the second one provides a basis for more effective adjustments. An investigation of the first problem begins naturally with an examination of the surface manifestations of man's occupation of the region, that is with a study of the features of the cultural landscape. No other science, it may be noted in passing, gives systematic attention to the development of the cultural landscape.

The detailed and authoritative treatment of these problems requires field work, especially the preparation of maps showing the present utilization of the land, the highest utility of the land, and the distribution of all significant cultural features. Some of these features are not mapped by other field workers, while others, though mapped, are not treated in a manner suitable for geographic purposes. Neither of these basic problems can be solved in terms of natural factors alone, and the geographer should be very cautious not to attach

undue weight to such factors. The habits and aptitudes of the people, markets for their products, prices, transportation facilities and rates, land values, the availability and cost of labor, the competition of other regions, laws and governmental policy—all these and various other factors may help to bring about a particular adjustment to environment. The solution of the geographic problem requires the use of these psychological, economic, political, and other facts. So used, they take on a geographic quality, just as geographic facts, when used in certain ways, acquire the character, for example, of economical or historical items. No science enjoys exclusive possession of all the data with which it deals, and whether a given fact is geographic or not may well depend, it seems to me, on how it is used. Detailed regional studies of the kind to which I have referred are needed almost everywhere; not alone in the newer lands in which an incoming population is seeking adjustment, but quite as much in older areas, where, in some cases, the people are out of adjustment to their environment. They are needed also in areas devoted chiefly to manufacturing no less than in areas used for farming or grazing, and in the former they require a special order of skill, for where the industrial structure of a community is complex, its environmental contacts are likely to be involved and obscure. Detailed field studies in the economic geography of restricted areas will form, I believe, the chief road to further advancement of our science. Especially will they in time establish a firmer foundation for fruitful studies in the more or less nebulous realms of the political and social geography of specific regions.

Urban Geography.—Urban geography really is a phase of regional geography, and studies of individual cities may be prosecuted no less advantageously than those of other areas from the viewpoint of human ecology. Two fundamental problems in the geography of any city will sufficiently illustrate this method of attack: (1) The interpretation of the city landscape, which is simply a special type of cultural landscape. In this connection one should consider such things as the structure or ground plan of the city; its street pattern; the location of its transportation lines; the distribution and character of its manufacturing; wholesale, retail, residential, tenement, and other districts; and the location of its parks and other open areas. To account for the use of land in these different ways within a city area is as truly geographic as to account for the use of land for different crops in a rural district. (2) An appraisal of the present activities and the prospects of the city in the light of its environment. Its stage of development, the advantages and disadvantages of its site and situation, its relations to supporting lands and to rival urban centers: these are some of the factors that must be taken into account in making the valuation.

HISTORICAL GEOGRAPHY.—I can best make clear my views concerning the scope and relations of historical geography, the remaining branch of the subject according to the scheme here suggested, by reference to my own experience in that field. One of the courses in history which I took as a student dealt chiefly with the expansion of the American people. It stressed the social, political, and economic conditions of the great movement across the continent from the Atlantic seaboard to the shores of the Pacific, but occasional references, of absorbing interest to me, were made to the more obvious geographic relations that were involved, such as the influences of land forms and of waterways. This course, perhaps more than any other single influence, led me later to undertake the development of a group of courses in Geography dealing somewhat systematically with the relations between earth conditions and earth resources, on the one hand, and the settlement and development of the country on the other. In connection with this work I came to realize that American history, on its material side, fundamentally is largely a record of the adjustments of a rapidly expanding people to varied environments. I also realized in time that in almost any unit area of the country one may trace a continuous evolution of the environmental relationships of the people. It would be a great mistake to suppose that in the course of these ever-shifing relationships the natural environment has remained unaltered; that, as some have put it, the natural factor is the constant, and the human factor alone the variable. An environmental complex may be changed profoundly, even in a short interval of time, by the operation of natural forces and especially by the activities of man. Even though its physical aspect changes but slowly, its economic utility may change repeatedly and greatly for many reasons, such as the discovery of mineral wealth, the application of new methods of land utilization, improved transportation, and altered relations to other regions—to mention only a few causes. More and more I have come to feel, as a result of this work on the United States, that it is the special task of the historical geographer to describe and so far as possible to explain this evolution of man's environmental relations. To me, indeed, historical geography has come to mean simply the geography of the past,—human ecology in past times. Unstead also recently characterized historical geography as "the geography of the past," but to him this phrase has a broader meaning, as he would not restrict geography to human ecology. Historical geography, the geography of the past, helps to show the significance of past geographic conditions in the interpretation of present-day geographic conditions. It provides the key to many environmental relationships that have persisted after the occasion for them has passed. It introduces, so to speak, the "third dimension"

into geography. It helps us to see that the present adjustments of people to their environments represent only a stage in a ceaseless process of evolution, and it throws some light on the changes that are before us. By helping to teach that no adjustment of man to the earth is permanent, that the only permanent thing is change, it answers, by the way, one phase of that oft-repeated question about the future of geography. Some eminent geographers, though they assign to geography a wider scope than here advocated, imply that when at last the explanatory description of the earth shall be completed the task of geography will be finished. On the contrary it will come to an end only if and when human life disappears from the earth.

Historical geography deals chiefly with the *past* and with the *evolution in time* of those phenomena which it treats, and so partakes of the distinctive characteristics of history. It restricts its attention to man's relation to his environment, and so is altogether human ecology. It has thus the distinctive qualities of both geography and history.

Just as I formerly encouraged my students to begin their treatment of a region in all cases with an explanatory description of its physical features, one after another, so I encouraged them, when at last they came to a consideration of man, to start invariably with the earliest settlement of the region, and trace, step by step, the development of its human geography. I now believe that in all cases we should begin with the consideration of man's environmental relations, and proceed to their analysis, classification, and interpretation; that in studies in geography proper we should begin with *present day relations,* and invoke the past only when necessary in order to interpret the present; and that in studies in historical geography we should begin with the *relations of the earliest stage of adjustment* and then consider those of successive stages, each in turn.

The Indefinite Boundary Zone.—Since the different phases of human activity are connected with one another organically, all facts relating to the life of a community may be said to have a near or remote geographic significance. This constitutes, I believe, a real menace to the further development of geography in an orderly and scientific manner. As in recent years we have stressed increasingly the study of man, there has arisen a real danger that all sorts of human facts will be claimed for geography without the establishment of any relationship to the earth. Illustrations of this tendency need not be cited, for it must have been apparent to all thoughtful observers. It is not the human fact which is geography, any more than it is the environmental fact, but rather the relation which may exist between the two. Geography is a science of relationships. I readily agree that in studying the affairs of men from that point of view which is geography, it is

exceedingly difficult to determine where we pass from geography into the social sciences. The boundaries are never lines; at best they are indefinite zones. The more remote applications of earth relations doubtless are very important in many cases and geographers have just as much right to make them as have, for example, the economists or the sociologists. But let us not appear to claim as a constituent part of the domain of geography the remote realms into which we may venture. And especially, as already urged in effect, let us build our approaches carefully and methodically, so as not to leave gaps in the sequence of relationships that will invalidate our conclusions. Let us not, either, claim exclusively for geography functions which it shares with other subjects. The claim recently has been made, for example, that geography alone can give an understanding of the conditions and problems of the peoples of other lands. Certainly this claim cannot promote a sympathetic attitude toward geography on the part of historians, economists and others who know that their subjects also can make highly important contributions along this line. In this particular case let us seek merely to show, through the excellence of our regional studies, that to view the life of nations and of communities in relation to their environments provides one indispensable prerequisite to understanding their problems and their attitudes, and so helps to pave the way for intelligent sympathy and for effective cooperation. The claims to usefulness which geography legitimately can make are sufficiently impressive.

Conclusion.—I may summarize my convictions as follows:

(1) I believe that the age-old subject of geography, though it has lost many specialties, still seeks to cover too much ground, and that it would benefit by frankly relinquishing physiography, climatology, plant ecology, and animal ecology.

(2) I believe that a motivating theme, an organizing concept, is required which shall permeate geography, and give to all its divisions a distinctive point of view. I believe that the problem of the causation of the distribution of surface phenomena, urged by some, and the task of the explanatory description of regions, advocated by others, alike fail to meet this requirement, and that the problem of human ecology may have the vitalizing, unifying influence needed.

(3) I believe that those relationships between man and the earth which result from his efforts to get a living are in general the most direct and intimate; that most other relationships are established through these; that, accordingly, the further development of economic regional geography should be promoted assiduously, and that upon economic geography for the most part the other divisions of the subject must be based.

(4) I believe that geography has been too much a library subject, and too little a field subject. I hold that the field is the geographer's laboratory. I believe that we have made only a beginning in the development of rigorous, scientific methods of field work in geography, as distinct from field work in physiography and geology, and that the development of a thoroughly effective technique in field work is perhaps our greatest immediate need. Since most of us are "rebuilt geologists," do we not, in general, *study* the geological items and merely *observe,* in more or less haphazard fashion, the geographical items? Precisely how should one study in the field those relationships which are truly geographic?

(5) I believe that much of our so-called geographical exposition is something else, that to be truly geographic a discussion must involve from beginning to end an explanatory treatment in orderly sequence of human relationships, and that the development of a satisfactory technique in exposition is only less important than the perfection of field methods.

(6) I believe, finally, in spite of the iconoclastic spirit which may seem to have pervaded my remarks, that we have every reason to congratulate ourselves upon the outlook for geography. It is making remarkable progress in America, though still in a state of flux. By one road or another it will come fully into its own through further experimentation. The road which to me seems most promising is that denoted by human ecology.

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LAWS OF TEMPERATURE*

STEPHEN SARGENT VISHER

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INTRODUCTION.—This treatise is a summary of the temperature aspect of climate only. Concise statements of the ways in which certain aspects of climate differ from place to place are given in some texts and treatises dealing with meteorology and climatology. Similar brief statements of how nature acts have been helpful in advancing many other sciences. These "laws," as they have been termed, call attention to what is known and often reveal the inadequacies of current knowledge. An attempt is here made to state, explain and illustrate what, in lieu of a better short title, may be called "laws of climate." Many of these are obviously not strictly analogous to some of the laws of the more exact sciences, but the term "law of nature" is not applied merely to precise quantitatively demonstrable laws. The aim of this paper is to point out and explain those relations which correspond, in so far as the nature of the subject permits, to the laws of other sciences. Like those laws, these relations are subject to frequent modification, and seldom do they operate in a dominating way. However, neither do many laws of physics, for example, operate except under restricted conditions of temperature, pressure and purity of substance. Many of the laws here given have been expressed or implied

*The laws of wind and moisture will be summarized in a later number.

in one or more of the treatises or texts consulted[1] or in technical papers A number of these laws seem not to have been concisely stated in print, however, and many have not been fully explained. In order to have fewer omissions and more accurate and clearer statements of these laws and their causes, criticisms were obtained from a number of persons. Grateful acknowledgment is here made to all who have so generously assisted in making this study more worth while.*

[1] *Meteorologies:* Davis, (1894), Russell (1895), Waldo (1894) (1896), Moore, J. (1894, 1910), Moore, W. L. (1910), Milham (1912), Hann, Lehrbuch der Meteorologie 3d ed., (1915), McAdie (1917), National Research Council (1918), Shaw Manual of Meteorology, pt. IV, (1919), Humphreys, Physics of the Air (1920); *Physiographies:* Salisbury (1907, 1919) Tarr-Martin (1914); *Miscellaneous:* Ward, Climate (1908, 1918); Hann; Handbook of Climatology (1903); Huntington: The Climatic Factor (1914); Henry and others, Weather Forecasting in the U. S. (1916); Salisbury, Barrows and Tower, Elements of Geography (1912), Shaw and others, Meteorological Glossary (1918); Ferrel, Popular Treatise of Winds (1889); Shaw, Weather Forecasting (1911, 1919); Taylor, Australian Meteorology (1920); *Physics:* Ganot (1905), Watson (1899), Crew (1909), Kimball (1917), Poynting-Thompson (1911).

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LAWS CONCERNING THE HEATING AND COOLING OF THE EARTH

DISTRIBUTION OF HEAT IN POINT OF TIME.—1. *Climate depends upon the nature and effectiveness of solar radiation.*—This is true in so far as temperature and light are concerned, because the great source of heat on the surface of the earth is solar radiation, and also because the amount and type of solar radiation received and retained by the earth varies from time to time. The temperature of any place depends upon various factors, considered in subsequent laws, upon the amount and type of solar radiation and upon the amount of atmospheric and terrestrial absorption. None of these four factors operate at a constant rate in point of time or place. Geographic variations are discussed below. Widespread variations from time to time in the amounts of radiation and absorption are likewise a part of climate. The amount of radiant energy emitted by the sun also varies. A cycle of 11 or 12 years is recognized and there is evidence of both shorter and longer cycles, especially one of about 33 to 35 years.[2] Apparently there are other variations in the amount of energy emitted by the sun within periods of weeks or months.[3] In addition to variations in the amount of solar radiation, there is clear evidence of variation in the type of emanations, as is shown by the intermittent occurrence of auroral displays. Ultraviolet rays also do not always make up the same proportion of the emanations. Long term variations in either the amount or the kind of radiation reaching the earth, even though slight, undoubtedly affect climate in a fundamental way.[4] Sudden changes of pressure of a remarkable type occur over extensive areas and may possibly be due to sudden variations in solar radiation.[5]

[2] Marvin, C. F.: Theory and Use of the Periodocrite, *Mo. Weather Rev.*, Vol 49, pp. 115-132, esp. p. 131, 1921; Clough, H. W., An approximate seven-year cycle in terrestrial weather with solar correlations, Ibid. Vol. 48, pp. 593-596, 1920; Henry, A. J., Temperature Variations in the U. S. and Elsewhere, Ibid, Vol. 49, pp. 62-70, 1921; Huntington, E., Earth and Sun, 1923; Clayton, H. H., Solar Variation and Weather at Buenos Aires, *Smithsonian Misc. Collect.*, Vol. 71, 1920, and Helland-Hansen and Nansen, Temperature Variations in the North Atlantic Ocean and the Atmosphere, *Smithsonian Misc. Collect.*, Vol. 70, 1920.

[3] Abbot and others, The Solar Constant; *Mo. Weather Rev.*, Vol. 43, p. 212, 1915, and Vol. 47, pp. 1-3, 1919. Concerning the uncertainty of many of the daily variations in the Solar Constant, see Marvin, C. F., Forecasting the weather on short period solar variations, Ibid, Vol. 48, pp. 149-150, 1920.

[4] Huntington, E., The Solar Hypothesis of Climate, *Bull. Geol. Soc. Am.*, Vol 25, 1914, pp. 477-577, and Earth and Sun, 1923; Brooks, C. E. P., The Secular Variations of Climate, *Geogr. Rev.*, Vol. 11, pp. 120-132, 1921.

[5] Huntington, E.: Solar Disturbances and Terrestrial Weather, *Mo. Weather Rev.*, Vol. 46, pp. 123-141, 168-177, 269-277, 1918.

The amount of atmospheric absorption varies with the composition of the air. Changes in the water vapor, CO_2 and dust content of the air are particularly important as these are relatively active absorbers.[6] Water vapor is most important, being almost a full absorber for radiant energy sent out by a black body at a temperature of 212° F.[7] Nitrogen has no known absorptive power and oxygen absorbs only a few wave lengths other than those in the far ultraviolet.[8]

Variations in the amount of water vapor in the air are produced by changes in the temperature of the air and of evaporating surfaces, and in the distribution of land and water, and by variations in wind velocity. Modifications in the distribution of land and water affect climate in many significant ways, but are geologic in origin and are produced slowly. Changes in the average temperature are produced by variations in insolation and in the composition of the air, and by changes in the surface of the earth, and thus in the amount of absorption and retention of radiant energy. It has been suggested that variations in the amount of CO_2 in the air have been due to differences in the temperature of the sea, in which much CO_2 is dissolved; to variations in the activity of volcanoes, which emit much CO_2; and to differences in the rate of depletion of the atmospheric CO_2 by coal-forming plants and by the carbonation of rocks. The rate of depletion is greater when the continents are elevated, as at present, than when they are low and partly submerged, as they have been at many times during geologic history.[9]

[6] Fowle, F. E., Atmospheric Transparency for Radiation. *Mo. Weather Rev.*, Vol. 42, pp. 2-4, 1914 (a summary of earlier papers by Abbot and Fowle); Dines, W. H., The amount of radiant energy absorbed and reflected by the earth and its atmosphere, *Quart. Journ. Royal Meteorol. Soc.*, April, 1917 (Abstracted in Meteorological Glossary, pp. 331-333; Humphreys, W. J., The Physics of the Air, 1920, (Volcanic dust receives especial consideration). The efficacy of CO_2 as an absorber is discussed in numerous papers. Chamberlin gives a good summary to 1906 in Chamberlin and Salisbury: Geology, Vol. 2, pp. 655-677. See also Clarke, F. W., The Data of Geochemistry, 4th ed., 1920 (*Bull. 695, U. S. Geol. Survey*), pp. 49-50, 141-145, and Huntington and Visher, Climatic Changes, their Nature and Causes, pp. 36ff, 19, 139, 1922; also, Kimball, H. H., Variations in the Solar Radiation in the U. S., *Mo. Weather Rev.*, Vol. 47, pp. 769-793, 1919. (The efficacy of water vapor as an absorber is especially emphasized in this comprehensive, detailed paper).

[7] Shaw and others, *Meteorological Glossary*, p. 33, 1918. In the Smithsonian Meteorological Tables, 1918, p. 231, the absorption of different wave-lengths is given. It varies irregularly from 6% to 100% for lengths given out by terrestrial radiation, but for most of the lengths it approaches 100%.

[8] Humphreys, Physics of the Air, p. 81, 1920.

[9] Chamberlin and Salisbury, Geology, Vols. 2 & 3, 1906, as to variation in extent of lands. See also Willis, Salisbury and others, Outlines of Geologic History, 1910, and Schuchert, Paleogeography of North America, *Bull. Geol. Soc. Am.*, Vol. 20, pp. 427-606, 1910; and Pirsson and Schuchert, Textbook of Geology, Vol. 2, 1915.

Long-time oscillations in the amount of atmospheric dust accompany variations in explosive volcanic activity, and changes in the extent of dry land.[10]

Absorption by the earth's surface varies with the distribution of land and water, with the extent and type of soil, rock and vegetation, and with cloudiness and the amount of snow-cover. All of these vary from time to time, and thus help produce climatic changes. The climate of any period, such as that of the present, is affected by all these complex influences, and by others mentioned below. As these conditions vary, climate changes. Climatology comprehensively studied is thus distinctly a dynamic subject instead of a static one.

DISTRIBUTION OF HEAT OVER THE EARTH.—*Effects of Latitude and Altitude.* 2. *Half of the earth is receiving heat from the sun at any given moment.*—Because of the rotation of the earth, there is a progressive change in the half which is heated by insolation. The amount of heat received per unit of time varies from a maximum in the area where the sun's rays are vertical to a minimum where they are tangent to the earth's surface.[11] Indeed at tangency there is almost no heating due to direct insolation because almost no energy is absorbed and only absorbed energy is effective in raising temperatures. At any given time the rays are nearly vertical (60° or more) over about one-fifteenth of the earth's surface. This proportion receives about 1.2 calories per square centimeter per minute on clear days from direct solar radiation.[12] It likewise receives radiation from atmospheric water and dust which have absorbed or reflect part of the solar radiation.[13] Indeed, in the tropics, one-half of the total energy received is from diffused or reflected

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[10] Schuchert, C., Climates of Geologic Time, pp. 265-298 of Huntington's, The Climatic Factor, *Carnegie Institution Publ.* 192, 1914, and (for Dust), Humphreys, loc. cit., pp. 569-603.

[11] The intensity of insolation varies with the sine of the sun's altitude. At the equinoxes, it varies as the cosine of the latitude. (Hann, J., Handbook of Climatology, Vol. 1 (tr. by Ward) p. 93, 1903.)

[12] 63% of 1.92 calories, Abbot, Fowle and Aldrich, The Solar Constant of Radiation. *Mo. Weather Rev.*, Vol. 43, p. 212, 1915. "From March 10 to Sept. 10 the heat received from the sun and sky on clear days on each square meter of horizontal surface (at Washington, D. C.) is equivalent to the energy required to run twenty-five 40-watt electric lamps for 7 hours." (Kimball, H. H., Measurements of Radiation, Ibid, Vol. 43, p. 610, 1915.

[13] Dines, W. H., (*Quart. Journ. Royal Meteor. Soc.*, April 1917) estimates that the atmosphere absorbs nearly one-tenth as much solar radiation as does the earth itself. It also absorbs nearly 3/4 of the radiation from the warmed earth and reflects back about 1/10. Only about 1/6 of the terrestrial radiation escapes to space directly.

light.[14] The amounts of radiation (solar and atmospheric) received daily by the earth's surface vary notably with latitude, humidity, and seasons.[15] (See Law 8.)

3. *Normal temperatures decrease with increase in latitude, except just north of the equator, nearly 1° F. for each degree of latitude* (about 1° C. for each 2° of latitude) because insolation diminishes as the angle at which the sun's rays strike the surface of the spherical earth becomes smaller.[16] With this change there is greater reflection, an increase in the area over which a bundle of rays is spread, and of chief importance, an augmentation of the distance which the rays must travel in penetrating the atmosphere. Rays entering the atmosphere at a small angle often are reflected away from the earth. Penetration is also reduced by atmospheric absorption and diffraction or scattering of light rays.*

The average air temperature at the surface of the earth is about 59° F. (15° C.); near the equator it is 80° F. (27° C.) or above, except on the Pacific Ocean where it is about 77° F. (25° C.). The average along the tropics is about 74° F. (23° C.); in mid-latitudes it is perhaps 50° F. (10° C.), and in polar areas 10° F. (12° C.) or less.[17]

In more detail, the mean temperatures are given as follows by Hann:[18] (The Fahrenheit equivalents are given just below the Centigrade figures.)

N. Pole	80°N.	70°N.	60°N.	50°N.	40°N.	30°N.	20°N.	10°N.	Equator.
—20°C.	—17	—10	—1.2	5.8	14	20	25	27	26.6
—4°F.	1	14	30	42	59	68	77	81	80

10°S.	20°S.	30°S.	40°S.	50°S.	60°S.
26°C.	23	18	12	5	—1°C
79°F.	73	64	54	41	30

Were it not for the distribution of heat by winds and ocean currents, tropical temperatures would be much higher and polar temperatures much lower than now, possibly about 131° F. (55° C.) for the equator

[14] Hann, loc. cit., p. 81. See also Very, F. W., Atmospheric Radiation, *Bull. G., U. S. Weather Bureau*, 1900.

[15] Kimball, H. H., Variations in solar radiation in the U. S., *Mo. Weather Rev.*, Vol. 47, pp. 783-784, 1919.

[16] The variation of 1° F. per degree of latitude has been verified in the United States by A. D. Hopkins in his study of the flowering of plants. See "The Bioclimatic Law," *Mo. Weather Rev., Suppl.* 9, 1918, also *Scientific Monthly* 8, 495-513, 1919 and *Mo. Weather Rev.*, Vol. 448, p. 355, 1920.

* See Law 18 beyond.

[17] These figures are from Bartholomew: Physical Atlas, Pt. 3, Meteorology, 1899, as are many similar figures below if not credited to some other source.

[18] Hann, loc. cit., pp. 200-202.

instead of 80° F. (26° C.) and —108° F. (—78° C.) for the poles, instead of about 0° F. (—18° C.) as now.[19]

The decrease in temperature with increase in latitude is not at a uniform rate. It is disturbed by variations in the proportions of land and water, highland and lowland, the amount of water vapor, cloudiness and storminess in the different latitudes, and by differences in ocean currents. On the average the ocean is cooler than the land except in high latitudes where the reverse is true. According to Zenker marine climates are 8.5° C. (15° F.) colder than continental climates at the equator, 7.3° C. (13° F.) colder at latitude 20, 2.3° C. (4° F.) warmer at latitude 40, 8° C. (14° F.) warmer at latitude 60, and 14° C. (25° F.) warmer at latitude 70.[20] Cloudiness generally lowers surface temperatures although it does not do so in winter in some cold regions.[21] Clouds in tropical latitudes reflect, on the average, more than half the solar radiation incident upon them.[22] Investigations in middle latitudes indicate that there is a reflection of 70%.[23] Nevertheless the climate of places in higher latitudes such as the British Isles, which receive much heat from the ocean, are kept mild in winter by being cloud-covered. In such places the effect of the clouds in retarding the escape of heat is more important in winter than is the lessening of insolation which they cause. Storminess increases upward convection, which in turn causes so much heat to be lost by radiation into space that stormy areas and belts tend to be abnormally cool, except in winter in high latitudes. This is in spite of the fact that the cloudiness associated with lows restricts the loss of heat, and the poleward blowing winds bring in much heat.[24]

4. *Normal temperatures fall with increase in altitude about 1° F. for each rise of 330 feet (1° C. for 600 ft. or 183 meters, or .6° C. for 100 meters*). The rate differs somewhat for mountains, plateaus and

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[19] Salisbury, R. D., Physiography, revised ed., p. 455, 1919.

[20] Quoted by Hann, loc. cit., p. 212. In Die Lehrbuch der Meteorologie, 3rd ed., 1915, p. 153, Hann gives Liznar's computations of the probable temperatures of land and water hemispheres at various latitudes.

[21] For a good discussion of the lowering of temperatures produced by cloudiness in the lower latitudes (between 30′ N. and 30″ S.) See Huntington: *Bull. Geol. Soc. Am.* 1914, pp. 581-87. The influence of clouds on temperatures in northwestern Europe is discussed in Hann, loc. cit., p. 136.

[22] Blair, W. R., *Mo. Weather Rev.*, Vol. 44 p. 194, 1916.

[23] Balloon investigations carried on recently by the Smithsonian Institution in southern California, L. B. Aldrich, *Smithsonian Misc. Collect.*, Vol. 69, No. 10, Washington, 1919; Author's Summary reprinted in *Mo. Weather Rev.*, Vol. 47, p. 154, 1919.

[24] Huntington, E., *Bull. Geol. Soc. Am.*, Vol. 25, pp. 572-574, 1914.

plains, being 1° F. for each 265 feet of ascent on mountains, 290 feet on plateaus, and 365 feet on plains (1° C. for each 180 meters on mountains, 200 meters on hills and 250 meters on plateaus).[25] For dry "free air" the decrease is 1° F. for each 300 feet (1° C. per 165 meters, or 6° C. per 1,000 meters), on the average, up to the base of the stratosphere, an elevation of about seven miles (11 km.).[26] At an elevation of about 2,000 feet (600 m.) above sea level, the effect of altitude on temperature is appreciable, and at 4,000 feet it is marked, resulting in a short frost-free season in mid-latitudes. Lofty mountains, even in the tropics, have frigid temperatures at their summits, though not a polar climate. The normal decrease in temperature with increase in altitude is due partly to the increased distance from the chief source of atmospheric warmth, the warmed earth, but chiefly to the decreased absorption by the atmosphere of radiation from the sun and of radiation and conduction from the earth. The atmospheric substances which absorb radiation (water vapor, dust and CO_2) all decrease notably in amount with increase in altitude, and as has been remarked, wherever there is little water vapor, CO_2 or dust, there is little absorption. Since radiant energy which is not absorbed does not raise air temperatures, high altitudes cool rapidly and become cold at night, and indeed even during the day, except where the sun is shining upon an absorbing surface. The thinness of the air, with the consequent fewer molecules to scatter the rays, also aids in the escape of heat.* The decrease in nocturnal temperature with increase in altitude is at a greater rate than the decrease in daytime temperatures. The decrease is also at a greater rate on the clear leeward sides of mountains than on the cloud-covered windward sides.[27] This disparity is due in part to the heat liberated at condensation on the windward slopes, and to the effects of foehns on leeward slopes. In the free-air, upward convection helps produce a progressive decline in temperature, since more heat is lost by expansion than is obtained by absorption or conduction. Furthermore, whenever convection is taking place, part of the air at any moderate altitude has recently arrived from a lower altitude. If the rise is rapid, inertia may carry such air far beyond the level of equilibrium and so make it much colder than the surrounding air. However, this condition soon results in a settling of the comparatively

[25] Hann, Lehrbuch der Meteorologie, 3rd, ed., p. 126, 1915.
[26] Humphreys, loc. cit., p. 38.
* See Law 17, beyond.
[27] Hann, Handbook of Climatology, Vol. 1, p. 249, 1903.

dense abnormally cold air to a level where it is neither abnormally dense nor cold.[28]

Effects of Winds and Ocean Currents.

5. *Winds are important in affecting local temperatures, especially along coasts in the higher latitudes, and at night.* Windward coasts in high latitudes are on the average abnormally warm and leeward coasts abnormally cold. Much heat is carried from place to place over the surface of the earth by the winds. In winter many places in high latitudes frequently receive more heat from the wind than by insolation or from the radiation of heat stored up in soil or water. At night there is no insolation and on densely cloudy days in high latitudes, there is but little. When the surface of the ground is cold or snow-covered or the water is ice-covered, they give up only a little heat. The importance of the wind in high latitudes is suggested by the statement that from the poles to latitude 52° the earth's surface receives more heat from atmospheric radiation than by insolation.[29] Even when the sun is shining brightly, a locality may be cold if winds bring in a large body of cold air. Hence the direction of the surface winds often strongly influences the temperature at any place, especially in middle and high latitudes or near the coast.[30] For example, the northeastern part of the United States is remarkably warm in summer partly because southern winds prevail there, while the summers of northwestern Europe are kept comparatively cool by the northwesterly winds prevalent there at that season. Likewise the North Pacific coast of North America has abnormally cold summers partly because strong west or northwest winds from the cold northern Pacific Ocean prevail then.[31]

In the absence of surface air movement, there is little passage of heat by conduction from air to soil, rock or water or in the other direction, because stagnant air has a low thermal conductivity. This is one reason why the surface is hotter on a calm day than on a windy one and why the lower air is colder on a calm night than on a windy one. On windy nights, air cooled by contact with cold ground is soon mixed with warmer air. Thus, although there is more cooling by conduction on a windy night than on a calm one because of the greater contrast between soil and air temperatures, a sufficiently greater quantity of

[28] For further discussion of this explanation of the vertical decrease in temperature see Humphreys, W. J., A Bundle of Meteorological Paradoxes, *Journ. Wash. Acad. Sci.*, Vol. 10, pp. 153-171, 1920.

[29] Hann, loc. cit., p. 116.

[30] Hann, loc. cit., p. 70, states, "Few districts may be said to have their own climate" because of the importance of winds.

[31] Hann, loc. cit., p. 178.

air is involved so that the temperature of none of it becomes so low as that of the lower air on a calm night.

6. *Ocean currents help to warm windward coasts in high latitudes, and to cool those in low latitudes.*—Much heat is transferred by the movement of sea water. High latitude coasts are usually warmed by heat carried there by the oceanic circulation. Because of the influence of the wind, the agency which transfers the heat from the water to the land, this warming is chiefly felt on the windward coasts. Among the surface currents two may be mentioned: Winds from off the "Gulf Stream Drift" warm northwestern Europe 10° F. (5.5° C.) or more in midwinter.[32] Without its influence navigation would be interfered with by ice that would then accumulate occasionally even in the eastern ports of Great Britain. On the other hand, the Humboldt Current chills the coast of Peru and northern Chile. However, the upwelling cold oceanic waters there, as along other coasts in Trade Wind latitudes, is the chief cause of the coldness of such a current, rather than the rapid movement by the winds of cold water from high latitudes.[33] The active evaporation by the dry Trades is another cause of the coldness, both directly and also by making the surface layers more dense than the fresher but colder water below, which is crowded upward by the sinking of the denser surface water.

Possibly of more significance than surface currents is the deep-sea circulation. All the ocean is surprisingly cold, except the surface, because of the sinking and spread of cold water from high latitudes. The average temperature of the ocean, when all the depths are considered, is less than 40° F. (4° C.). In past geologic ages high latitudes have occasionally been much warmer and more equable than now. Indeed, magnolias and figs have grown in Greenland. If vast quantities of tropical heat were transferred poleward beneath the surface by a reversal of the deep sea circulation, some such mild climate would result.[34] Such a reversal might be produced by a notable increase in the salinity of the ocean especially in low latitudes or by an increase in its temperature especially in high latitudes. The present surface currents from the tropics lose most of their heat by radiation and conduction to the air in low middle latitudes. However, surface currents

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[32] Salisbury, loc. cit., p. 470.

[33] Hann, loc. cit., pp. 185-187. See also Murray, J., The Ocean, 1912, and Brooks, C. F., Review of papers dealing with climates of Western coasts in the tradewind belt, *Geogr. Rev.* Vol. 11, pp. 633-634, 1921.

[34] Chamberlain, T. C., On a possible reversal of deep-sea circulation, *Journ. of Geol.* Vol. 14, pp. 363-373, 1906. See also Visher, S. S. *Bull. Geol. Soc. Am.*, Vol. 32, pp. 429-436, 1921.

may in times past have been more effective in transferring heat poleward than at present. Now, perhaps chiefly because of the retarding influence of cyclonic storms in mid-latitudes, the poleward movement of tropical waters is so slow that comparatively little heat reaches polar regions in this way.[35] If cyclonic storms were far less numerous than now the Westerlies would become more like the Trades in steadiness of direction, and the poleward movement of warm water would be much augmented, thus making possible mild polar climates where the distribution of land and water was favorable.[36] If during the past the deep sea circulation was of the "reversed" type at the same time that the Westerlies were steady at the surface, polar climates would have been especially mild.

7. *Windy places are commonly cooler than less windy ones otherwise similar* because: (1) Wind increases evaporation, and (2) increases the dispersal of local heat by conduction, except when the wind is extraordinarily hot. (3) Much surface wind has recently come from higher latitudes or altitudes and is cooler than the air it displaces. Wherever friction or topographic relations temporarily prevent wind, warm air accumulates whenever heating by insolation is greater than loss of heat by radiation. This is commonly the case in places which receive intense insolation but little heavier air (wind) to force the warm air to rise.* There are three chief exceptions to this law: (1) Areas in middle and especially those in high latitudes are often warmed by wind from the open ocean in winter or from the direction of the equator; hence windy places in high latitudes are often warmer than calm places. (2) Depressions are often cooler during calm nights than on windy ones, because cold air accumulates in depressions during calm nights.† (3) Many places are occasionally warmed by foehn winds.

Effects of Earth's Rotation, Shape and Inclination.

8. *Seasons of temperature occur in middle and high latitudes,* because of the revolution of the earth about the sun and the constant inclination of its axis to the plane of its orbit. As the axis maintains a practically constant direction in space at an angle of about 23½° to

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[35] Helland, Hansen and Nansen, Temperatures of the North Atlantic, *Smithsonian Misc. Collect.*, Vol. 70, #2537, 1920. Huntington and Visher, Climatic Changes, their Nature and Causes, pp. 174-176, 1922.

[36] Huntington and Visher, loc. cit., pp. 166-187.

* See Law 18, beyond.

† Similarly snow-covered surfaces are often cooler on calm nights than on windy ones partly because stagnant air in contact with cold snow cools to a lower temperature than that reached by a mixture of surface air and the warmer aid of moderate altitudes such as obtains on windy nights.

the ecliptic, the northern hemisphere is tipped toward the sun at one time, and six months later, when the earth is in the other side of the orbit, it is tipped away from the sun. The hemisphere tipped toward the sun receives more vertical and nearly vertical rays than the other and hence is warmer. In other words, the north-south shifting of the zone of greatest insolation accompanying the revolution of the inclined earth produces most of our changes of seasons. For example, in the United States, Minnesota receives six times as much radiation per unit area on June 21 as on December 21, and Louisiana two and one-half times as much on June 21 as on December 21. During a year a unit area in Louisiana receives 7 per cent more radiation than one in Minnesota, receiving 36 per cent more in the colder six months but 11 per cent less in the warmer three months. In July, Minnesota receives 20 per cent more than Louisiana. The arid southwest receives almost twice as much radiation as the northeast in winter and nearly 25 per cent more in summer. For example, South Carolina receives only about 75 per cent as much radiation per unit area in a year as does more sunny New Mexico. New Mexico leads each month in the year but more in the colder months and in July than in the other months, because of cloudiness in South Carolina then. The highest average amount received in gram calories per minute per square centimeter is 700 on June 21 in the arid southwest. The lowest is a little less than 100 on December 21 along the northern border and in the Great Lakes region.[37]

Although the earth is nearer the sun and receiving one-fifteenth more insolation in January than in July, the Southern Hemisphere does not receive a greater amount of heat in a year than the Northern. The earth moves with a sufficiently greater velocity along its orbit when nearest the sun as compared with its velocity when farthest away (in July), so that it receives as much heat when it is more than the average distance from the sun as it does when it is less than the average.[38] Indeed, the temperature of the earth as a whole increases from January to July nearly 2.7° F. (1.5° C.) while its distance from the sun is increasing. This is chiefly because of the greater land area in the Northern Hemisphere.[39]

Seasonal changes of temperature have been far less extreme during most of the better known epochs of the geologic past than they are at present. Indeed, freezing temperatures apparently did not prevail even in moderately high latitudes, at least not along the coasts, except during

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[37] Kimball, H. H., cited in note 15.

[38] Hann, loc. cit., pp. 93-101.

[39] Ibid, p. 201.

the several colder or Glacial periods.[40] Students of celestial mechanics insist that there has been no great change in the position or inclination of the earth's axis since the present solar system was organized. It is altogether unlikely that the higher latitudes could have been warmed sufficiently by the escape of heat from the interior of the earth to compensate for the lack of direct insolation in winter. Leading geologists estimate that the earth's interior probably is about as hot now as formerly.* Yet today the escape of heat is normally negligible.[41] In ancient times when high latitudes had a mild climate they must have received the necessary heat through the agency of atmospheric or oceanic circulation. A general " planetary " circulation of the atmosphere like that of the present seems called for by the distribution of insolation. A change in the oceanic circulation appears much more likely than many of the other changes hypothecated. If the ocean were distinctly warm in high latitudes, seasonal changes would be much lessened. The change in the temperature of the ocean might be due to a change in the amount of heat received from the sun or to a change in the amount of heat held in by the atmosphere. The amount held would fluctuate with the composition of the air, with storminess, and with the extent of land and water. Chamberlin[42] has developed the hypothesis advanced earlier by Tyndal, Arrhenius and others, that the alternation of glacial periods and warm climates in high latitudes is chiefly due to fluctuations in the CO_2 content of the air and to accompanying fluctuations of the moisture content. More atmospheric CO_2 would mean a somewhat greater retention of heat and thus more water vapor accompanied by a further increase in heat retention. Huntington[43] reports evidence of a change in storminess and in the location of storm tracks, and points out that heat retention would alter with storminess. Both Chamberlin and Huntington consider modifications in the distribution of land and

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[40] Barrell, Joseph: Rhythms and the Measurement of Geologic Time, *Bull. Geol. Soc. Am.*, Vol. 28, pp. 745-904, 1917; citation on p. 827. Schuchert, C.: Climates of Geologic Time in the *Climatic Factor*, pp. 265-298, 1914, Reprinted in *Smithsonian Annual Report*, 1914.

* Chamberlin, T. C., personal communication.

[41] The mean temperature of the earth's soil is estimated by Trabert to be raised by conduction from the internal heat of the earth by the trifling amount of 0.1°C. Bowman: Forest Physiography, p. 60, 1911.

[42] Briefly stated in Chamberlin and Salisbury: Geology, Vol. 2, pp. 665-667; Vol. 3, pp. 433-436, 1906. However see Clarke: Data of Geochemistry, 4th ed., pp. 142-145, 1920.

[43] Huntington: *The Climatic Factor*, Carnegie Institution, 1914; and The Solar Hypothesis, *Bull. Geol. Soc. Am.*, Vol. 25, 1914. pp. 477-577. Fuller evidence is presented in Climatic Changes, 1922 and in Earth and Sun, 1923.

water important contributory factors. Chamberlin considers the reversed deep-sea circulation, mentioned above, as the probable source of much of the extra warmth present in high latitudes during the mild periods of the past. This reversal he attributes in part to the influence of increased CO_2 in the air with its resultant greater retention of heat, and hence higher oceanic temperatures. Several other agencies have been suspected of being important in producing climatic changes.[44]

9. *The rotation of the earth is such that nearly all parts are lighted and heated by solar radiation for approximately twelve hours and then have darkness for a similar period.* High latitudes, and especially the polar regions (one-twelfth of the globe), are partial exceptions to this rule, as are mid-latitudes near the solstices.[45] However, the oblique angle at which the sun's rays penetrate the atmosphere and strike the surface in high latitudes prevents such excessive heating as would result in low latitudes if the period of heating there were much longer than it is. If the days were 16 hours long in low latitudes, life of the present sort probably would be impossible in the drier regions because protaplasm would be killed by the high temperature. In all latitudes, the coldest normal temperatures occur about sunrise, and the warmest, sometime after mid-day.[46]

10. *Because of the spheroidal shape of the earth and the inclination of the axis, days and nights vary significantly in length in middle and high latitudes.*—They are always the same at the equator and nearly the same to about latitude 20.[47] The disparity increases with the latitude. In July (northern hemisphere) the days average 13.9 hours in

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[44] See Humphreys: The Factors of Climatic Control; *Physics of the Air*, pp. 556-630. Humphreys advocates the efficacy of atmospheric dust. Ekholm, N., (On the variations of the climate of the geological and historical past and their causes, *Quart. Journ. Royal Meteorol. Soc.*, 1901, pp. 1-61) considers variations in the obliquity of the earth's orbit as an important influence supplementing variation in the amount of CO_2. Several writers have considered variations in the distribution and height of the land as the chief and direct cause of the changes of climate. (See Harmer, Influence of winds upon the climate of the Pleistocene, *Quart. Journ. Royal Meteorol. Soc.*, Vol. 27, pp. 303-305, 1901. (Summary), and Clarke, Data of Geochemistry, loc. cit., and Brooks, C. E. P.: Continentality and Temperature, *Quart. Journ. Royal Meteorol. Soc.*, April 1917, and Oct. 1918 (30 pp.), Schuchert, loc. cit., discusses the chief hypotheses advanced before 1914; and Huntington and Visher, Climatic Changes, 1922, all the more important hypotheses.

[45] For the length of day in each latitude and for each day in the year see *Smithsonian Meteorol. Tables*, Washington, 1918.

[46] Meissner reports, *Mo. Weather Rev.*, Vol. 48, p. 39, 1920 that the minimum comes 30 minutes after sunrise from May-September; 15 minutes after during spring and fall; and 10 minutes before in winter.

[47] Salisbury, loc. cit., p. 426.

length at latitude 30; 14.7 hours in length at latitude 40; 16 hours at latitude 50; 18.1 hours at latitude 60; and 21 hours at latitude 65.[48] Long days make summer warmer and long nights make winter colder than they would be if days and nights were always equal. The long summer days of high latitudes permit the growing of crops in extensive areas where those crops could not be grown if the days and nights were equal in length throughout the year (as they are at the equinoxes). Only at the poles is there six months of continuous day or night. All parts of the earth are lighted during one-half of the year.[49]

Effects of Character of Surface.

11. *Land is notably warmer than water in summer and cooler in winter. Land is usually warmer than water by day except in winter in the higher latitudes.*—Water becomes warm less quickly than land and retains heat longer.[50] The ocean thus is a great reservoir of heat in autumn and early winter.[51] In spring and summer it takes up heat from the air which it returns in autumn and winter. The ocean therefore notably affects the temperature of adjacent lands towards which the winds blow. Seas and large lakes act similarly until frozen over.[52] For example, the North Sea often raises the temperature of cold winds blowing from the continent to England as much as 18° F. (10° C.). Lake Ontario and the other Great Lakes likewise often warm cold winds several degrees centigrade.[53] Other effects of unequal heating of land

[48] Abbe, C., Relations between Climates and Crops, pp. 102-103, *Weather Bur. Bull.*, #36, 1905, for latitudes to 40°. For all latitudes see *Smithsonian Meteorol. Tables*, 1918, pp. 203-214.

[49] Not exactly; there are fewer long nights than long days, in the northern hemisphere, and the opposite in the southern hemisphere. This is due to the earth's elliptical orbit and its greater velocity of revolution when near the sun than when far away. Furthermore all parts of the earth receive sunlight for slightly more than half of the year because of the reflective effects of the atmosphere. The sun is visible when it is about 1° below the horizon. Hence in a year there are about 2/360 more hours of light than of darkness (Humphreys, W. J.: A Bundle of Meteorol. Paradoxes, *Journ. Wash. Acad. Sci.*, Vol. 10, pp. 168-170, 1921.)

[50] Several reasons why water heats and cools more slowly than land are given in Salisbury, Physiography, pp. 454-455, and in Ward, Climate, pp. 36-37.

[51] Pettersson: Meteorological Aspects of Oceanography, *Mo. Weather Rev.*, Vol. 44, pp. 338-341, 1916; and Brooks, C. E. P., cited in note 44 (Abstracted in *Mo. Weather Rev.*, Vol. 47, pp. 653-654, 1919.

[52] The ice will not be as cold as the air above it when that air is very cold, because of the tempering influence of the relatively warm water beneath the ice. Ice however is a very poor conductor of heat; hence ice-covered water bodies contribute heat to the atmosphere so slowly as to have little influence as a source of heat. See, Birge, E. A. Heat Budgets of American and European Lakes, *Transac. Wis. Acad. of Sci., Arts and Letters*, Vol. 18, pt. 1, 47 pp., 1914.

[53] Hann, loc. cit., pp. 179, 180.

and water are land and sea breezes and monsoon winds. Because the ocean is cooler than the land more than half the time, average temperatures are lower along the coast than inland, except in the higher latitudes. "The heat equator" is north of the rotational equator except near Australia because there is more land in low latitudes in the northern hemisphere than in the southern. The greater extent of arid land north of the equator is of especial significance because arid lands are much warmer than the ocean in low latitudes. It is chiefly for this reason that the northern half of the eastern hemisphere averages 4.5° F. (2.5° C.) warmer than the southern half, and the eastern hemisphere 1.8° F. (1° C.) warmer than the western.[54] In the higher latitudes, the ocean is warmer than the land, especially in winter. For example, in Europe between latitudes 47° and 52°, for each 10° of longitude farther from the west coast there is a decrease of 2.4° F. (1.3° C.) in mean temperature and a decrease of 5.6° F. (3.1° C.) in winter, but an increase of 1.3° F. (0.7° C.) in summer.[55]

12. *Snow or ice-covered areas are notably colder than similar areas not so covered except those immediately to leeward,* chiefly because air temperatures much above the freezing point will not occur where snow or ice is widespread. After a temperature of 32° F. (0° C.) has been attained, additional heat received by the surface air usually melts the ice, and becomes latent energy instead of raising air temperatures. Furthermore, the reflection from snow or ice lessens the effectiveness of solar radiation greatly, 40 per cent or even as much as 70 per cent, according to Abbot. A third factor reducing the temperature of snow-covered areas is the evaporation from the snow. Likewise the snow mantle is a good non-conductor and also a poor absorber of heat, and therefore interferes with the warming of the air by heat in the soil. These influences, together with the general dryness of the air in clear weather, often lead to low nocturnal temperatures over snowfields in clear weather.

13. *The vegetal cover affects temperature conditions.*—In forests the air is cooler by day and warmer by night, on the average, than in grasslands, and in other places possessing scanty vegetation. Vegetation absorbs much radiation and reflects some also. Likewise it interferes bodily with the escape of heat from below, which effect is especially prominent at night. Another important way in which vegetation modifies temperatures is in promoting evaporation, a cooling process. It is largely because of the greater evaporating surface which the leaves afford that the temperatures in dense equatorial forests average less

[54] Hann, loc. cit., p. 202.

[55] Ibid, p. 138.

than those at coastal stations.[56] Additional effects of vegetation on temperatures are given under other laws.*

14. *Diurnal and seasonal lag usually increases with latitude, at least in middle latitudes, and decreases with increased aridity.*—Lag is due to the fact that heating is delayed by the presence of ice, cold water, frozen or chilled soil and rock and that cooling is delayed by stored-up heat in water, rock, soil and water-vapor. There is less lag for atmospheric temperatures in arid regions than in humid regions because: (1) There are fewer clouds and less other atmospheric moisture to interfere with radiation; (2) there is little water vapor available for evaporation or freezing; (3) there is a greater exchange of heat by conduction between the atmosphere and the land because the scanty vegetal cover is less effective than the denser vegetation of more humid lands in maintaining a layer of stagnant air between the land and the atmosphere. Another cause of more effective conduction in arid regions is the greater exposure of firm rock there than in humid regions. Rock is a much better conductor than soil.[57] Air over the water reaches its maximum temperature sooner after the time of maximum heating than air over land (about 1 P. M., instead of about 2 P. M.).[58] This is largely because, (1) water heats and cools so slowly that it has only a small diurnal range and hence little positive effect on the diurnal temperature of the air. Thus over the water air temperatures cease to rise almost as soon as insolation decreases. The temperature of the surface of the land is usually higher than that of the air for some time after noon, so that radiation and conduction from it continue to raise the temperature of the air. (2) Since water is a better reflector than land, the decrease in the angle of incidence after noon soon means a much greater reflection from water than from land with a correspondingly greater decrease in effective insolation per unit area on the water. (3) Increased evaporation with higher temperatures also tends to prevent a further rise in water temperatures.[59] In the intermediate zones the amount of seasonal lag averages about a month, but increases with

[56] Ibid, p. 138.

* See Laws 14, 17, 19 and 23.

[57] Patten, H. E., Heat transference in Soils, *U. S. Bur. of Soils, Bull.* 259, p. 49, 1909.

[58] Hann. loc. cit., p. 13.

[59] Only a fraction of the heat entering open water raises its temperature; the rest causes evaporation. The fraction used for evaporation rises rapidly with increased temperature of the water and is very high in tropical seas. (Hann, loc. cit., p. 131). In northern United States and northern Europe, however, according to Birge, E. A., *Trans. Wisc. Acad. Sci.*, Vol 18, 1914, more of the heat is used to raise the temperature than to evaporate the water.

latitude chiefly because of the corresponding increase in the amount of surface water, snow, and ice.

The lag is greater in water than in air and is still greater at moderate depths in the soil. Unless shallow, water is commonly warmest an hour or two before sundown, and two or even three months after the summer solstice. It is coldest an hour or two after sunrise, and two or three months after the winter solstice. The vertical circulation, and hence the amount of lag, is affected, however, by the salinity where average water temperatures are near 39° F. (4° C.), as fresh water is densest at 39° F. (4° C.), while oceanic salt water is densest at 28° F. (2° C.). Depth and heating being equal, the lag is greater in fresh than in saline water. The lag in soil varies with depth. At the greatest depth commonly reached by the diurnal change of temperature (about two to three feet, depending on the kind of soil and on the extent of the atmospheric diurnal range), the highest temperature is at night and the lowest by day. The seasonal change is normally inappreciable below 35 to 70 feet (11-22 meters), even in regions of great seasonal range, and is much less than 35 feet in the tropics with their small seasonal range of temperature, and in polar regions with their frozen subsoil.[60] Near the bottom of the zone of seasonal change in temperature in the soil wherever that zone is deep, the maxima usually occur about five months later than they do in the air above.

RANGE IN TEMPERATURE.—*Diurnal Range.*

15. *Diurnal range in temperature is greatest, other things being equal, where and when day and night are of equal length. Hence it normally decreases with increase in latitude, except near the equinoxes, when the reverse is true.*—When nights are much shorter than days nocturnal cooling does not last long enough to reduce the temperature so much as when nights are longer. On the other hand short days seldom become warm enough to produce a marked diurnal range. Near the equinoxes, diurnal range tends to increase with latitude, because the decrease in absolute humidity characteristic of increase in latitude allows more rapid heating and cooling in higher latitudes than in lower latitudes. These normal relationships between daily range and latitude are interfered with in the cyclonic storm belts because intense storms occasionally increase daily range notably. Furthermore, three influences locally interfere with the normal seasonal occurrence of the greatest ranges. Instead of coming at the equinoxes, some places have a greater average range in winter, because of augmented storminess at that season, with resulting occasional sharp temperature changes within 24 hours. Places with dry seasons often have the greatest ranges in the

[60] Bowman, I., Forest Physiography, p. 60, 1911.

dry months since aridity favors a wide range. (See Law 17, beyond.) Finally, seasonal changes in wind direction give some places near coasts a smaller range at one season than at another. (See following law.)

16. *Diurnal range in temperature increases with decrease in the influence of the ocean or of lakes* as water tends to prevent the temperature from rising notably by day and from falling low at night. The average diurnal range in the surface waters of the ocean varies from 2-5° F. (1.1°-2.8° C.).[61] On the other hand, the average diurnal range over the land is more than 12° F. (7° C.) and the temperature of the surface soil or rock is often several degrees colder or warmer than that of the air a few feet above. The air over water is kept warm at night in three ways: (1) The large amount of heat given up by the water, due to its high specific heat. (2) The vertical movements, by which warmer and hence less dense water from below replaces the partially cooled surface water. (3) The abundance of atmospheric moisture and the frequent cloudiness above water bodies checks the loss of heat by radiation at night.

17. *Diurnal range in temperature increases with aridity, on the average.*—A large range is less common in humid than in arid regions because humid regions have more atmospheric moisture, greater cloudiness, more evaporation, more condensation, more dense vegetation and more moist soil. In humid regions atmospheric moisture greatly hinders surface absorption and loss of surface heat by radiation, and in addition clouds often check insolation by day and loss of heat by radiation at night. Furthermore, in moist areas much heat is used during the day to evaporate water. This latent energy is returned to the air as heat when condensation takes place, as when dew is formed at night. The greatly increased evaporation at higher temperatures is an important factor in preventing temperatures from rising much above 100° F. (38° C.) in moist regions. Twice as much moisture can be contained in a given space at 108° F. (42° C.) as at 90° F. (32° C.). The formation of fog and clouds at night often prevents frost by liberating heat in condensation as well as by checking the loss of heat by radiation. The influence of cloudiness on nocturnal cooling is well illustrated by data reported by Hellman.[62] On a clear night in Germany, the average temperature one-half meter above the surface is 6.7° F. (3.7° C.) higher than at the surface, while with an overcast sky there is no difference. Furthermore, when the sky is one-tenth overcast the

[61] Ward, R. De C., Climate, p. 37; quoting from Challenger Report. For an excellent summary see: Buchan, Alex., Meteorological Results of Challenger Expedition, *Proceed. Royal Geogr. Soc.*, Vol. 13, pp. 137-156, 1891.

[62] *Mo. Weather Rev.*, Vol. 48, p. 38, 1920.

temperature contrast is one-tenth less than on a clear night. Dew formation with its notable release of latent heat of vaporization is also often significant in preventing low temperatures. Sometimes it prevents frost. Indeed, the lower the relative humidity at 8 P. M., the greater is the expected cooling by morning.[63] The influence of vegetation and soil in affecting conduction has been mentioned. (Law 14.)

Even in deserts certain influences prevent excessively high air temperatures by day: (1) The loss of heat by radiation is rapid because of low humidity and slight cloudiness; (2) the rate of radiation increases rapidly with increases in temperature (varying as the fourth power of the absolute temperature for black bodies—Stefan's Law); (3) conduction of heat into the earth is favored by the abundance of bare rock; (4) the prevalent convectional winds by day carry much heat aloft; (5) the increased dustiness induced by the high winds and whirlwinds checks insolation. These five influences and the shortness of the days, usually prevent the occurrence of temperatures higher than about 120° F. (50° C.). Low temperatures at night are delayed, not prevented, by the dust because most dust in deserts is coarse and low and much of it settles during the prevailingly calm nights. Furthermore the dust radiates heat readily and before morning is colder than the surrounding air, which it then helps to cool by conduction. Whereas the daily range in air temperature in humid areas is often less than 10° F. (5.6° C.) and commonly less than 20° F. (11° C.), in warm deserts it is usually more than 30° F. (16° C.), often more than 50° F. (28° C.), and not rarely 70° F. (39° C.). Indeed dark-colored rocks in the Sahara often experience a diurnal range of nearly 176° F. (80° C.).[64]

18. *Diurnal range in temperature increases with altitude up to the snow-line for places similarly exposed, except on some valley slopes.*—This is because at higher altitudes there is progressively less air, less water vapor, less CO_2 and less dust. Decrease in these latter substances is significant because together they absorb nearly all of the radiant energy absorbed by the air.[65] Air pressure is significant in this connection because molecules of all gases scatter or diffract an important

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[63] Hann, loc. cit., p. 145. For a much fuller discussion of this point see Smith, J. Warren,: Predicting minimum temperatures from Hygrometric Data, *Mo. Weather Rev.*, Supplement, No. 16, 1920.

[64] Hann, loc. cit., p. 147, quoting Walther.

[65] According to Ganot's Physics, (p. 630) CO_2 has 90 times the absorption power of ordinary air, and water vapor has 70 times the absorption power of dry air. For a fuller discussion of this subject, however, see Humphreys, Physics of the Air, pp. 88, 606-608, 1920.

fraction of solar radiation.[66] Above an elevation of two miles (3 km.) the scattering is chiefly molecular. Below that level, dust is important.[67] Scattering interferes with the passage of radiant energy. Hence, because of lessened atmospheric absorption and lessened diffraction, a larger fraction of solar radiation is available at high than at low altitudes for daytime warming of favorably exposed surfaces. For the same reasons the loss of heat by radiation is very rapid at night, and by day from places in the shade. Certain conditions at high altitudes are adverse to large diurnal range, but are not sufficient to prevent a general increase in range with increase in altitude.[68] For example: (1) In spite of the frequently large ranges of temperature of favorably exposed rocks, air temperatures are slightly affected because the air normally passes too rapidly, because of the strong winds, to be affected appreciably by conduction or radiation from or to the small rock surface. (2) The "down drainage" of cool, heavy air at night often results in valleys being cooler than adjacent heights of moderate elevation. The cool air moves outward from the hillside and slightly downward as the colder air lower in the valley settles. It is replaced by somewhat warmer air from greater distances from the cold surface. The accumulation of cold air in valley bottoms results in the zone of highest temperatures being found some distance up on the valley sides, though below the normally colder hilltops and peaks. Such warmer zones are sometimes "frost free" in the fruit-growing season.[69] In free-air the diurnal range decreases with height. There is often a difference of 5° F. (3° C.) between the surface temperature and that of the air five feet (1½ meters) above, and sometimes in dry areas there is a difference of 14° F. (8° C.).[70] This is because air is a much poorer radiator than soil or rock.

19. *Diurnal range in temperature increases with decrease in vegetation:* (1) Bare soil or rock, especially if dark-colored, as it commonly is, absorbs more radiation than do most plant-covered areas. There is much reflection from leaves, many of which are light-colored and most of which are somewhat shiny. (2) There is more evaporation

[66] Abbot, Fowle and Aldrich, *Proceedings Nat'l Acad. of Sci.*, June 15, 1915, pp. 331-33, and, more fully, in *Annals of the Astrophysical Observatory, Smithsonian Institution*, Vol. 3.

[67] Angstrom, A., Scattered radiation from the sky, *Mo. Weather Rev.*, Vol. 47, p. 797, 1919.

[68] Hann, loc. cit., p. 238.

[69] See Cox, H. J., Thermal belts in the North Carolina Mountain Region, and their Relation to Fruit Growing, *Annals Assoc. Am. Geographers*, Vol. 10, pp. 57-68, 1920.

[70] Hann, loc. cit., p. 42.

from vegetation than from the average soil or rock-covered area. (3) A small part of the energy absorbed by plants is used in photosynthesis becoming latent in carbohydrates. (4) Vegetation hinders the escape of heat from the soil, and from the entrapped air, especially at night and thus delays cooling sufficiently to prevent minima so low as those reached in bare areas, or in the air above the vegetation. The escape of heat is reduced by the absorption of radiation from the soil by the subaerial parts of the plants and the subsequent return of part of this energy to the earth by downward radiation. The greater humidity of the air near plants as compared with more remote air acts in the same way. Furthermore, vegetation interferes bodily with convection. The way in which vegetation decreases the loss of heat at night by conduction has been mentioned in Law 13. Because of these influences the diurnal range in forests averages several degrees less than in adjacent fields.[71] However, when deciduous trees leaf-out in spring frost is perhaps sometimes induced by the sudden increase in evaporation.[72]

20. *Diurnal range in temperature differs with differences of slope.*—A slope inclined toward the noonday sun is heated more during the day than one not so inclined but both cool to nearly the same temperature by morning. Steep slopes usually have less range than gentle slopes equally well situated in respect to insolation, because on steep slopes warm air is more quickly removed by upward convection during the day, and cold air by drainage downward at night and thus the temperature of the surface on steep slopes is more nearly equal that of the free-air, than is the case with gentle slopes.

Interdiurnal Variability.

21. *Interdiurnal temperature variability increases with latitude up to subpolar latitudes if other conditions are equal.*—In tropical latitudes nearly all days have similar temperatures, as do the nights. In high latitudes there is great contrast among both the days and the nights. This variation is the result of: (1) Increased disparity in the length of day and night with increase in latitude; (2) the fact that in middle and high latitudes, wind direction is much more significant in changing local temperatures than in low latitudes, where almost all winds are warm; (3) storms also increase the variability, and storms apparently increase in frequency and intensity, on the average, with latitude to subpolar latitudes. One of the ways in which storms cause this variability is in producing interdiurnal changes in cloudiness.

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[71] Fernow, Abbe, and others, Forest Influences, *Bull. 7, Forest Service, U. S. Dept. of Agri.*, 197 pp., 1893.

[72] Mayer, A. G., Radiation and absorption of heat by leaves, *Am. Jour. Sci.*, 3rd series, Vol. 145, pp. 340-346, 1893.

Seasonal Range. 22. *Annual or seasonal range in temperature increases with latitude to the region of persistent snow and ice* because of the increased significance of the changes in the angle of insolation, and the increased contrast in length of day and night. Long days in summer tend to produce high maxima. Long nights in winter tend to produce low minima. There is a rapid lowering of minima with increase in latitude and a less rapid lowering of maxima. As minus departures from the normal temperature are usually greater, and often twice as great as the plus departures, low minima are more important than high maxima in producing great seasonal range. The regions of extreme range are therefore on the continents in high latitudes where the winters are long but where snow does not persist throughout the year and thus prevent high maxima; *i. e.,* in the interiors of Northern Asia (range 170° F.; 94° C.), and in northern North America (range 160° F.; 89° C.). The extreme range in the Sahara is only 90° F. (50° C.). Near the equator the average annual range, based on monthly means is 5° F. (3° C.) or less; for latitude 20, about 13° F. (7° C.); for latitude 30, about 18° F. (10° C.); for latitude 40, about 26° F. (13° C.); and for latitude 50, about 46° F. (25° C.).[73] The average annual range for the land based on extreme maxima and minima is about 40° F. (22° C.) near the equator, about 80° F. (44° C.), in latitude 30, and about 120° F. (67° C.) in latitude 60.[74]

23. *Annual or seasonal range in temperature becomes greater with decreases in the influence of the oceans, in the amount of moisture present in the air, soil, or on the surface, and with reduction in vegetation,* because conditions favorable for high temperatures by day, favor high summer averages and maxima, and conditions favorable for low temperatures at night favor low winter averages and minima. (See Diurnal range, Laws 15-20 for reasons.) Marine climates have little range compared with continental climates. The average annual range in marine climates is 15° F. (8.3° C.) for latitude 35 N., and 14.8° F. (8.2° C.) for latitude 60. For continental climates, latitude 40 has a range of 52° F. (29.5° C.), and latitude 60 a range of 88° F. (48.6° C.). The mean for these different latitudes gives the range for marine climates as 14.8° F. (8.2° C.), while that of the continental climates is 70° F. (39° C.), or nearly five times as great.[75] The contrast between continental and marine climates is on the average less in latitudes 0-40 than in higher latitudes, because annual range decreases with latitude. Nevertheless it remains notable.

[73] Supan, quoted by Hann, loc. cit., p. 135.

[74] From Bartholomew's Charts, loc. cit.

[75] Hann, loc. cit., p. 142.

American examples of seasonal range follow:[76] Western Oregon has a normal seasonal range of only about 18° F. (10° C.), while South Dakota has a range of 60° F. (33° C.). The extreme ranges for these places are about 85° F. (46° C.) and 165° F. (91° C.), respectively. Because of the increased dominance of continental conditions, seasonal range commonly increases toward the east on land areas in the westerly wind belt, although the eastward increase in humidity, as in the eastern United States, tends to counteract this influence. Examples of the increase in range toward the east are: Southwestern Arizona has a monthly range of 30° F. (17° C.) and Northwestern Georgia, one of 35° F. (19° C.) the extreme ranges at Yuma, Ariz., and Columbus, Ga., are 100° F. (55° C.) and 112° F. (62° C.), respectively. Nevada has a monthly range of almost 5° F. (2.8° C.) less than Illinois or Pennsylvania. Some stations in southern Minnesota have less range than some in northern New York, in spite of the tempering influence of the Great Lakes. An illustration of the influence of vegetation on annual range is the fact that in Austria the average temperature in the forest is 2° F. (1° C.) lower in summer than outside of forests, while in winter the difference is negligible.[77]

24. *Annual or seasonal range increases with altitude up to the snowline,* because at high altitudes heating of slopes inclined toward the sun is less interfered with by dense atmosphere, dust and moisture, than at lower altitudes, while cooling at night and in the winter is facilitated by the normally strong winds and by the reduced atmospheric interference with the escape of heat. Lofty plateaus have a greater range than lowlands in similar latitudes. For example, stations with an elevation of 5,000 feet (1500 m.) in eastern Oregon have a seasonal range of about 10° F. (5.5° C.) above that in eastern Washington at an elevation of less than 1,000 feet (300 m.), but otherwise similar.[78] Above the snowline, however, the seasonal range is not so great because summer temperatures are prevented from rising nearly so high as they do below the snowline.

25. *Seasonal range in temperature is affected by topography.*— Slopes inclined sharply toward the midday sun are warmer in summer than those not so inclined, while in winter they may be equally cold, and thus have the greater range. Favorably situated valleys are usually warmer than nearly level stretches (although they may sometimes

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[76] Charts of Normal Temperatures and Extreme Temperatures for the United States, *U. S. Weather Bureau,* 1912.

[77] Hann, loc. cit., p. 31.

[78] Charts of Normal Temperatures and Extreme Temperatures for the United States, *U. S. Weather Bureau,* 1912.

be notably colder at night—see No. 18, above). Such valleys are normally warmer because: (1) Foehn breezes or winds often prevail; (2) the more effective heating of those portions which receive vertical insolation may more than compensate for the less effective heating of slopes not so favorably situated for heating as are level tracts. (3) Radiation from the sides of warm valleys interferes with loss of heat by radiation from the valley bottom, or in case of a narrow valley, from the other side,[79] probably because of the larger radiating surface in proportion to the volume of air within the valley receiving the radiated heat. Some favorably located areas have their temperatures notably affected by reflection from water bodies, snow, or light soils. The maxima are often several degrees higher than those at nearby points.[80] The minima are usually as low, because diurnal and extreme minima normally occur at night. Furthermore, by day the sun shines at a lower angle in winter and the reflection thus affects a different area.

Variability from Year to Year. 26. *Variability or irregularity in temperature conditions from year to year and for corresponding months tends to increase with latitude nearly to the region of persistent snow, with aridity, with storminess, and with decrease in the influence of the ocean.*—Equatorial days and seasons resemble one another strikingly in so far as temperature is concerned, while in mid-latitudes, no year or season is "normal." Temperatures are distinctly more uniform in humid areas than in arid regions otherwise similar. Variability increases with latitude for a number of reasons: (1) Slight fluctuations in the effectiveness of insolation and radiation are more appreciable where little insolation is received than where much is received. Differences in cloudiness and precipitation produce fluctuations of this sort in high latitudes. (2) Changes from year to year in direction and velocity of the wind produce greater changes in temperature in high than in low latitudes, where nearly all winds are warm. Differences in storm paths and storm intensity produce many such changes in the average wind direction for the year. (3) In so far as storminess increases with latitude it helps to explain this law. The greater variability of weather in winter than in summer is largely due to greater storminess in winter. The stabilizing influence of snow and ice makes polar conditions somewhat more uniform in some respects than those in subpolar regions. Variability increases with distance from the ocean because of the lessening influence of that great stabilizer of temperature conditions. Variability increases with aridity because irregularity in the amount of clouds and surface water increases in

[79] Davis, loc. cit., pp. 31, 157.

[80] Hann, loc. cit., p. 40.

that direction. An exception to this latter rule occurs in extremely arid regions on the lee side of mountains where conditions are fairly uniform. Illustrations of this general law are Hann's statements that a 40-year record would be required in central Europe to obtain as accurate an average annual temperature as a two-year record from Java would give. In Siberia records for more than 100 years would need to be averaged to obtain a monthly average as accurate as a five-year record would give in Java. Eight hundred Siberian winters would give an average no more nearly correct than would 100 summers.[81]

[81] Hann, loc. cit., pp. 9, 10.